Development of China Vanadium Industry

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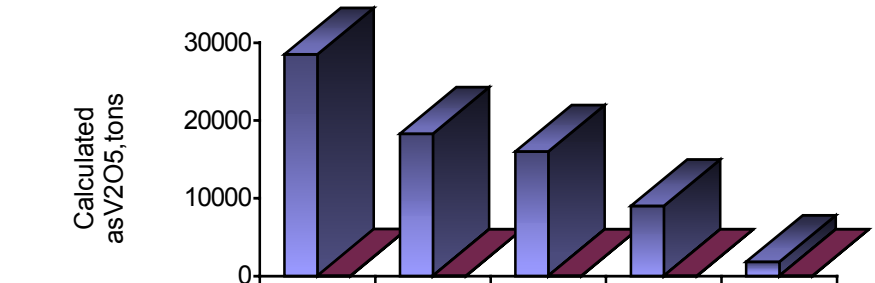
1 Brief introduction of China vanadium industry

China is one of the largest vanadium producing country in the world. Currently, there are seven countries in the world, which are South Africa, China, Russia, USA, Australia, New Zealand, and Japan, producing vanadium slag, vanadium oxide, and high ferro-vanadium. World vanadium production in 1999 is listed in Figure 1. Since 1980s, South Africa, Russia and China are the three major vanadium-producing countries. With Australia Windimurra vanadium project being put into production, it may take 9% of the world vanadium shares, and become one of the major vanadium producers. Except that USA and Japan are extracting vanadium from petroleum residue and Orimulsion from power generation plant, other producers are recovering vanadium along with the ore melting process.



	S.Africa	China	Russia	U.S.A	Others
Calculated as V2O5	28500	18300	16000	9000	1800
percent %	38.72	24.86	21.74	12.23	2.45

Figure 1 Vanadium production in the world (1999)

Notes: all data in the table except those for China are mainly referred to the USGS published statistics, and do not include V_2O_5 production of Australia Windimurra. which came onto stream in the end of 1999.

Panzhihua Iron and Steel (Group) Company (hereinafter referred to as Pangang) is the largest vanadium producer in China. If calculated as capacity of V_2O_5, Pangang is producing 74% of vanadium raw materials of the whole country, which accounts for 18% of the world production. Figure 2 shows the vanadium productions status in China. Chengde iron and steel company is another major vanadium producer in China, the production scale of this company is continuously increasing these years.

Development of China vanadium industry benefits mainly from the development and utilization of the vanadium and titanium magnetite ore in Panzhihua. With the vanadium atomization process putting into

practice in 1972, growing out of nothing, China has changed into a large vanadium exporter from a large vanadium importer since 1980. At present, the annual sales income of Pangang vanadium products is 407 million yuan. The foreign exchange earnings from export is 32 million USD per year. In 1998 it hits to 65 million USD. Vanadium has become the polar industry for Pangang only second to the steel industry. The following statements are mainly focused on the development and utilization of vanadium in Panzhihua to present the development of China vanadium industry.

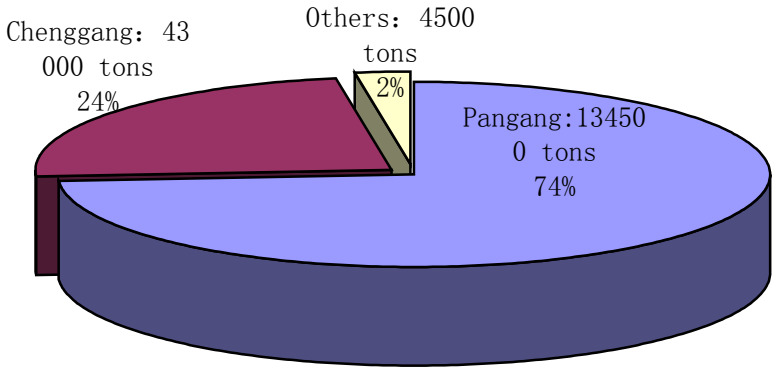


Figure 2 raw vanadium material productions in China

Around the world, vanadium consumption in steel industry amounts to 85% of its total consumption, other applications are in vanadium bearing titanium alloy and chemical industries. In steel industry, the proportion of vanadium consumption is illustrated in figure 3. The HSLA steel including pipeline steel for petroleum and gas transportation is around 55%, special steel including tool steel takes about 45%.

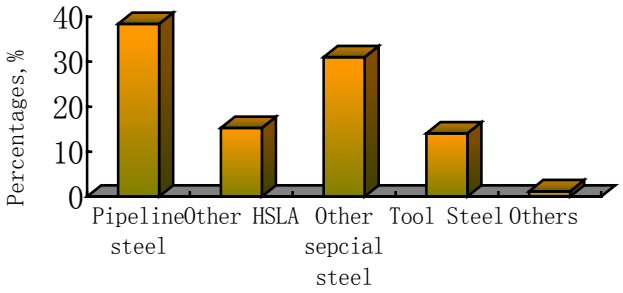


Figure 3 Vanadium Consumption in steel (1998)

The total vanadium consumption in China steel industry is around 2860 tons (on metal vanadium basis). 90% of vanadium consumption is in steel industry; the other 10% is used in catalyst, vanadium and titanium alloy, and pigment etc. In steel industry, 1500 tons metal vanadium is used in special steel melting; 1100 tons is used to make high strength low alloy steel. In recent years, vanadium consumption in vanadium contained

rebar is obviously increasing. Ferro-vanadium used in Pangang is 80% vanadium, the other producers are using 50%FeV and other type of ferro-vanadium.

Internationally, vanadium consumption strength is often used to express the application levels of vanadium in steel industry. Vanadium consumption strength is represented by kilograms of vanadium consumed per 1000 tons steel. Since 1980s, world vanadium consumption has been increased from 30 kg/1000t to 50 kg/1000t in 1998, increased by 67%. With the growing requirement for high strength, low weighted steel, vanadium consumption will be further increased. While the current vanadium consumption in China is only 20 to 25 kg per 1000t of steel, it's obviously lagging far behind the world level. Therefore, the potential is great.

The vanadium production in China ranks ahead in the world, but the application range, scale and level fall behind very much, which is not in compliance with its reputation as a large vanadium producer. To expand applications of alloy steel is the important mark for upgrading structure of steel products and technical levels of steel industry. Therefore, to popularize with great efforts the low alloy steel including vanadium-bearing steel, and to adjust the steel product structures is one of the important tasks for China to become a strong country in steel industry from a large steel producer.

2 Production of vanadium products in Pangang

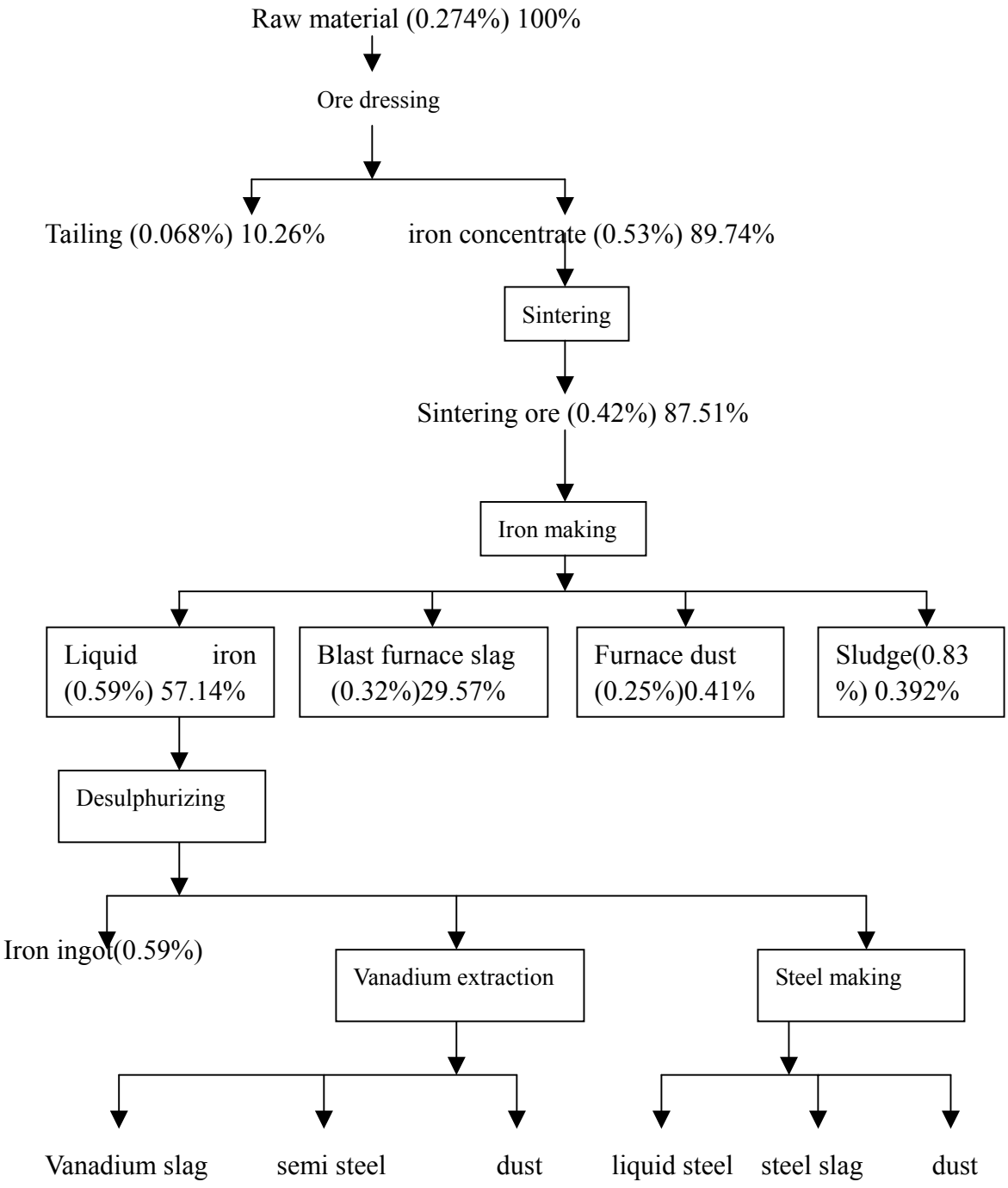
In China, vanadium producers are using basically the same process for vanadium extraction. The main difference between the production process of vanadium oxide in Pangang and other domestic counterparts is that we are using multi-hearth furnace instead of rotary kiln for roasting vanadium slag. The following block diagram is to illustrate the process flow of vanadium extraction in Panzhihua. Fig 4 shows the vanadium extraction process in Pangang. Data in the bracket is indicating grade of V_2O_5, and values beside it show the recovering rate.

Concentrated vanadium bearing iron ore separated from raw vanadium and titanium magnetite is conveyed to the sintering and ironmaking process to get vanadium containing liquid iron which afterwards is melted in converter to get vanadium slag. The recovering rate at this stage is 46.28%. If taking the comprehensive utilization of steel slag into consideration, the actual recovering rate is slightly higher than this figure; it can reach above 53%. Through the processes like roasting, leaching and precipitation, APV can be gained from vanadium slag. Then APV goes through processes like roasting, reduction etc. to get V_2O_5 and V_2O_3. Ferro vanadium is gained by further reduction of V_2O_5 and V_2O_3 in electric alumino-thermy process.

2.1 Production of vanadium slag

Pangang started extracting vanadium from liquid iron in 1972. Before 1995, the process of atomized vanadium extraction developed by Pangang itself with intellectual property owing to Pangang is adopted, the production scale is 75,000 ton/year, and the annual processed vanadium-bearing liquid iron is only 1.5 million tons. With the expansion of production scale, to increase processing ability of liquid iron and vanadium recovering rate, a new process recovering vanadium in converter with Pangang characteristics is developed, and the workshop with vanadium extracting converter

has been built up. At present, the processing ability of liquid iron is 3 million tons per year. The amount of produced vanadium slag is ranging from one hundred thirty thousand to one hundred forty thousand tons. With adoption of vanadium-extracting process in converter, the rate of vanadium oxidization has risen from below 85% to some 90%. The remaining vanadium in semi steel has been reduced under 0.04%. The technical parameters have improved significantly. Figure 5 is to illustrate the vanadium slag production since 1972, it can be seen therein that the production capacity of vanadium slag has increased a lot with the adoption of new technology.



(13.28%) (0.04%) (0.14%) (0.021%) (2.65%) (0.36%)

Figure 4 Process flow of vanadium extracting in Panzhihua

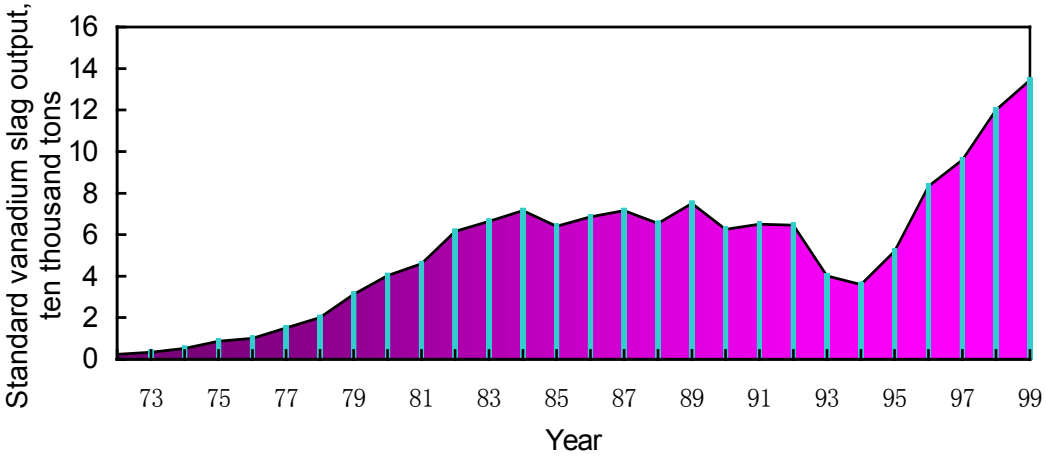


Figure 5 Production trends of vanadium slag in the past years

2.2 Production of V_2O_5 and V_2O_3

V_2O_5 workshop of Pangang was built up and put into production in March 1990. The present capacity is approx.3800 tons a year, including the production capacity of the Xichang Branch Company. The vanadium recovering rate of this process is 85%. To reduce production costs and improve production efficiency, a process of producing V_2O_3 was developed by its own effort in 1998. Together with the integration of imported equipment and technique, a V_2O_3 workshop with an annual output of 3350 tons was built up in 1998. The turnout of V_2O_3 in 1999 was 2180 tons. It's predicted that output in the year 2000 will achieve the design capacity. Figure 6 is to show production of V_2O_5 and V_2O_3in the past years.

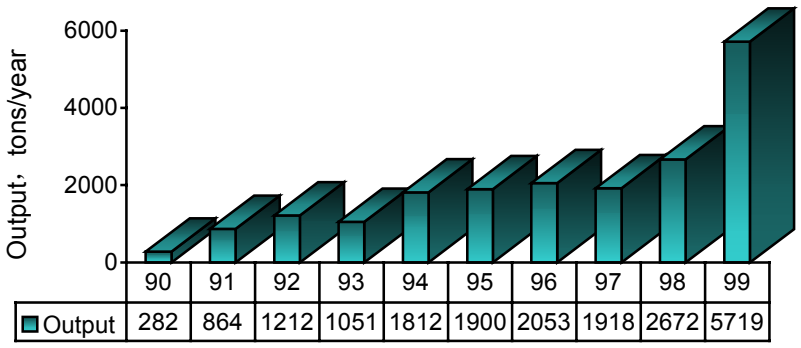


Figure 6 production of vanadium oxide of Pangang since 1990, calculated equivalent to V_2O_5

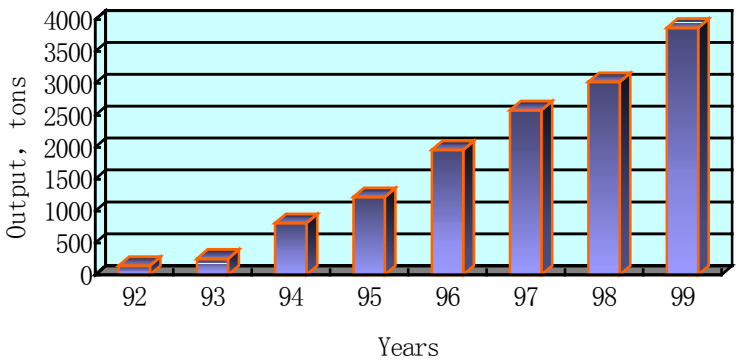


Figure 7 Ferro-vanadium productions in the past years, calculated equivalent to FeV80

2.3 Production of ferro-vanadium

In 1991, Pangang developed the production technology of 80% vanadium-containing ferro-alloy, and put into commercial use. The annual production capacity is 1300 tons, and the vanadium recovery rate is over 95%. In 1993, with the imported equipment from Luxembourg for producing high vanadium contained ferro-alloy through electric aluminothermitic process, the second production line was built up in Beihai , Guangxi Autonomous regain, of which, the capacity is 2000 tons. To meet various demands in the domestic market, Pangnag started to produce 50% ferro vanadium since 1998. Figure 7 shows the ferro-vanadium productions of Pangang in the past years.

2.4. Research and development on techniques for extracting and processing vanadium

In many years of science research and production practice, Pangang and other Chinese enterprises as well as some research institutes have carried out research works on production technology of vanadium slag, vanadium oxide and ferros-vanadium. The main achievements are as follows.

Techniques of extracting vanadium from vanadium containing liquid iron :

- Atomized vanadium extraction (developed in 1970s, applied until 1995)
- Process of vanadium extracting through sodium compounds (developed in the end of 1970s)
- Vanadium extraction in steel slag in 1980s, as one of mode of comprehensive utilization of steel slag
- Vanadium extraction in converter, developed in 1990s, started its application in production from 1995; the technical figures have reached the world advanced levels.

Techniques of vanadium oxide production from vanadium slag:

- Low temperature leaching, for production of ammonium poly-vanadate
- Multi-hearth roasting technique, developed in 1980s and still in application
- Production technique of V_2O_5

- Production technique of V_2O_3

Techniques for melting and further processing vanadium alloys:

- Aluminothermy process for producing FeV80 by using $V_2O_5$and V_2O_3
- Melting process for FeV50
- Producing ferro-vanadium by directly using vanadium slag, and steel slag containing vanadium in 1980s
- Production technique for vanadium carbide and vanadium nitride from 1990s till now

Through sustained efforts in many years, Pangang has achieved scores of researching successes in vanadium extraction and vanadium product development, and has formed series of extracting and processing techniques suitable for the characterized Panzhihua resources. Product varieties keep increasing, and recovery rate is improving year by year. The cost is going down continuously. Especially on development of process technology of vanadium extraction in converter, V_2O_3 and VN production, significant, creative achievements have been made.

In 1991, under laboratory conditions, by using ammonium poly-vanadate as raw materials, we have got vanadium carbide meanwhile FeV nitride has been produced by using high vanadium contained FeV as raw material as well. In 1997, in cooperation with Northeast University, Panagang used V_2O_3 as raw material to make vanadium nitride. The results show that under atmosphere pressure, the time of carbonizing reaction, that is, $V_2O_3 + 4C = V_2C + 3CO$, is shortened within 5 hours from 40 to 60 hours, and there is further potential to short the carbonizing time. The products have reached the international technical standards of the same kind products. Now, key breakthroughs have been made in production process and fine effects have been achieved in industry applications. An industry trial production line of 150 tons per year is under construction.

3. Applications of vanadium containing steel in China

3.1 Overview of application

With technological improvements in China steel industry and development of vanadium industry, the applications of vanadium containing steel in China have gained steady increase. Figure 8 is the production of vanadium-containing low alloy and micro-alloy steel in China since 1990s. The average annual growth rate is about 10%.

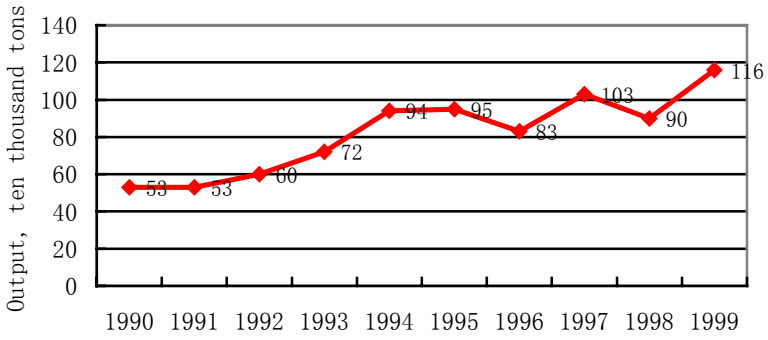


Figure 8 Production and developing trends of vanadium-containing low alloy steel in China

In recent years, the production of vanadium-bearing steel in China is continuously growing, the varieties are also increasing, especially the construction steel, pipeline steel, heavy rail steel, automobile steel and structure steel for train are in rapid development. The annual average productions of vanadium-bearing low alloy steel from 96-98 are indicated in figure 9. They are mainly produced by Pangang, Capital Steel, Anshan Steel, Baoshan Steel, Chongqing Steel etc. There are 12 enterprises having the production over 10,000 tons at the moment. With the popularity of vanadium-containing steel bars, a lot of medium sized enterprises like Chenggang, Bagang, Shuigang and Laigang etc. will become large producers of vanadium-containing steel bars within one or two years to come.

Relaying on the advantages of resource and technology, after many years of uninterrupted efforts, Pangang has developed scores of vanadium-bearing steel grades. The production of vanadium-bearing low alloy and micro alloy steel have taken above 50% of the total output of the same steel grades nationwide. Figure 10 is the productions of Pangang's vanadium-bearing low alloy in the past years

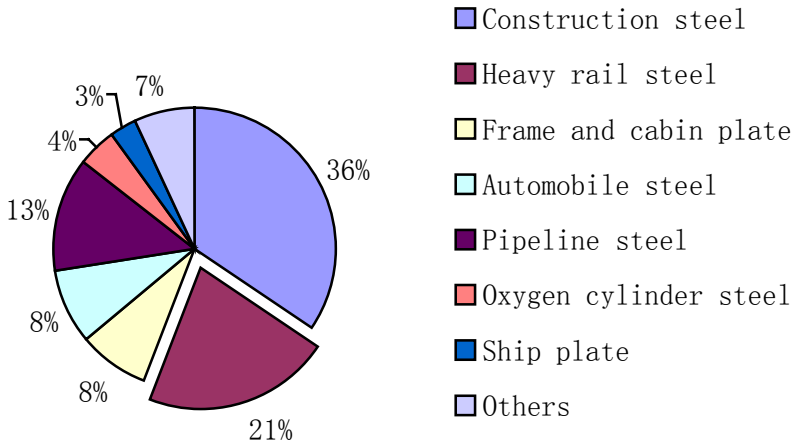


Figure 9 Distribution of vanadium-bearing steel grades

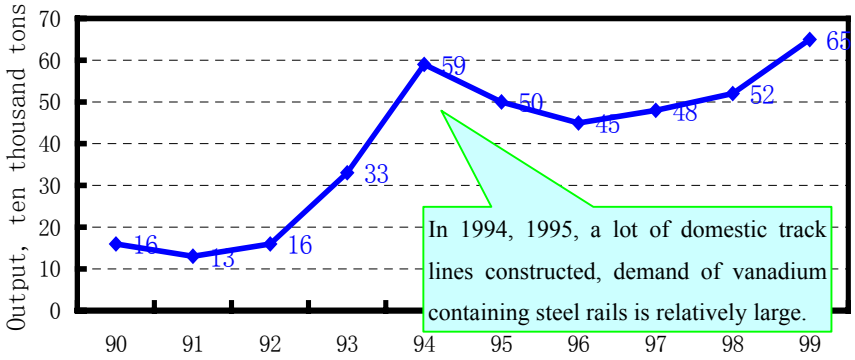


Figure 10 Production of vanadium-bearing steel of Pangang in the past years

3.2 Characteristics and applications of vanadium bearing steel

Vanadium additions in steel result in significant improvements in steel properties. It is indicated in practice that with 0.1% addition of vanadium in structure steel, the strength can be increased by 10 to 20 percent; the structures' weight can be reduced by 15 to 25%, and costs be reduced by 8 to 10%. If adopting vanadium-bearing high strength steel, metal structure weight can be reduced by 40 to 50%; the costs compared with normal structure steel can be reduced by 15 to 30%.

Researches show that vanadium additions in steel improve steel properties significantly in the following aspects except solid solution strengthening effect not in apparent manner:

1) V(CN) is of higher [%V] × [%N] in austenite. Vanadium has strong precipitation strengthening effects in low , medium ,high carbon steel.

2) Refining grain size through preventing austenite grain size growing in heat treatment, restraining the austenite recrystallization, strengthening γ--α phase transformation to gain the effects of refining grain size in steel.

3) Affecting over-cooled austenite transformations and improving the hardenability .Study shows that vanadium is not to delay ferrite transformation but to prolong bainite and pearlite transformation which differs from most alloy elements, meanwhile, vanadium has the function to improve the hardenability of steel which is t two times higher than same amount of molybedenium contained contributing to the hardenability .

Vanadium promotes the ferrite formation in HAZ of high strength steel, and therefore makes improvement of toughness. In high and medium carbon steel, the addition of vanadium microalloying obviously delay the pearlite transformation. Under the same cooling speed, more refined pearlite can be obtained, i.e. sorbite degree has been increased. Vanadium microalloying in hard wire steels can improve strength and toughness, and make it possible to partially or completely eliminate lead patenting treatment. In steel rail products ,to increase its service life , Slack Quenching (i.e. S.Q.) process technology has been developed . Experimental test indicated that pearlite is more wear resistant than tempered martensite and bainite ,and the smaller interlaminar space of pearlite, the better performance of wear resistance it has. With addition of appropriate amount of vanadium in steel rails ,its transformation curve moves right so as that sorbite in microstructure is easier to be realized when S.Q process technology is applied.

Vanadium as alloy and microalloying additions has many good effects on steel. Aforementioned is mainly the effects of vanadium on microalloying steel. Apart from this, vanadium has a lot of diversified effects in different steel grades of different applications. For example, to enhance ability to resist tempering in heat-treated steel, to improve red hardenability in high speed steel and the creep resistance in heat-resisting steel, as well as to improve corrosion resistance in

the corrosion resistant steel and to restrain the strain aging, etc..

3.2.1 Vanadium application in high carbon steel

In high carbon steel, vanadium microalloying is mainly implemented to produce heavy rail steel, bearing steel, and tool steel, mould steel etc. The currently produced steel grades with adoption of vanadium micro-alloying are mainly the rail steel.

Heavy rail steel is pearlite steel. The interlaminar space of pearlite and the size of pearlite colony dominate the rail strength, toughness and plasticity. Tensile strength and yield strength increase as the interlaminar space is getting less. Toughness is in relation with the pearlite colony size and cementite thickness. The research on effect of microvanadium on the properties of heavy rail steel shows that vanadium has effects such as refining austenite grain, refining pearlite structure and changing its structure formation, making precipitation strengthening effect ,.increasing strength and service life of steel rails.

Rails made from vanadium bearing steel rail in Pangang are vanadium microalloying hot rolled rail, off-line vanadium containing heat-treated rail and on-line vanadium containing heat-treated rail.

PD3 vanadium containing rail is a new generation vanadium microalloyed steel developed with Pangang's own efforts. Its strength is as high as 980MPa, the life span of it increases by more than 50% as compared with the normal C-Mn steel rails(U71Mn). After full-length hardening heat treated, the depth of hardening layer of HRC 33.5-42.5≥ 15mm, the minimum tensile strength of this vanadium microalloyed steel rail is up to 1275MPa, and the minimum elongation is 10%(δ_5). After many years of operations on the railway, the vanadium microalloyed steel rail has been showing fewer defects like spalling, wave wear, earlier wear to limit, etc. Even thought ,hardening on rail ends was omitted, but phenomenon of impression on rail end has not been found. The rail is found to have fine weldability. The comprehensive performances have reached the world advanced level. The wear resistance on tracks has been enhanced by three times than that of U71Mn. Figure 11 shows the production variations of PD3 rail through the years and the percentages in the domestic rail market.

In high-speed tool steel, vanadium is the integrate alloy element, such as W18Cr4V, W6Mo5Cr4V2 etc. The annul yield of the tool steel in China is about 4000 tons.

Either cold operated mould steel or hot-operated mould steel, most of them contain vanadium, such as Cr6WV, Cr4W2MoV etc. The average vanadium content is 0.47 to 0.68%. Vanadium in the steel can fine grain size, improve toughness, enhance hardness, red hardness, wear resistance, and reduce sensitivity to cracking.

Vanadium is also used in bearing steel. By the end of 1960s, inside China, series of MnV bearing steel were studied, such as GSiMnV, GSiMnMoV, GSiMnVRe, GSiMnMoVRe, GMnMoV, GMnMoVRe, etc. These steel grades are now being used in large amounts. The lifespan of MnV series of bearing steel and the fatigue strength are both higher than those of GCr15, and have reached the standard of the well-known Swedish SKF bearing steel.

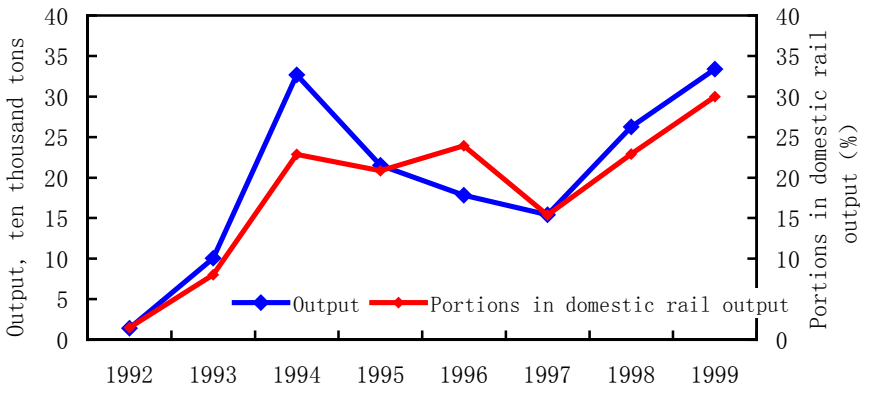


Figure 11 The production of PD3 rail and the percentages in the total output

3.2.2 Vanadium application in medium carbon steel

Vanadium improves both the strength and the toughness of medium carbon steels, and is widely used in these steels, such as vanadium-containing non-QT steel, medium carbon spring steel, and vanadium containing vessel steel.

Vanadium-containing non-QT steel

In recent decade, development and applications of non-QT steel in China have achieved a lot improvements. Research and developments of vanadium-containing non-QT steel are also active.

In automobile industry, the No. 2 Automobile (Group) Company in China has found fine effects in using F35MnVN instead of 40MnB QT steel to make the connecting rod of EQ6100 engine, replacing 40Cr with 48MnV steel to manufacture the crank shaft for the KOMINS engine, and using 12Mn2VB bainite steel to make the front shaft for automobile. An automobile company called Nanqi has applied F35MnVN steel in making universal yoke and annular pipe yoke, which are more difficult to produce. The No. 1 Automobile (Group) Company in cooperation with Angang, has made a non-QT steel 38MnVTi to replace 40Cr or 40MnB to manufacture automobile parts like half shaft.

The trial production of non-QT steel seamless tube is very active. For example in Chengdu Seamless Steel tube Factory, they have developed a steel containing vanadium for making thick-walled tube of the torsion axis used in heavy load truck and thin-wall N80 petroleum casing tube Nanqi has trial-produced medium carbon microalloy non-QT seamless tube. Different strength and various specifications of both cold and hot rolled products are evolved.

Tanggang has made researches on making non-QT 25MnSiV(Ti) of high toughness and high plasticity for manufacture of mine supporting facilities, the properties of which have met the level of the Germany 32Mn3 tempered steel. When used to substitute 20MnK steel to make 29U, it can save 29% rolled steel. The applications of non-QT

vanadium containing steel are continuously expanding to industries like lathe, petroleum machinery, civil firearms and plastic mould etc.

Microalloying is the technical core of non-QT steel. The adopted microalloying elements are V, Nb, Ti, B etc. in which vanadium as the microalloying elements accounts the majorities.

Among non-QT steel in various countries which can be utilized for statistics, the numbers of steel grades of known chemical components are 186, 158 of them are containing vanadium, amounting 85%, and 9 for niobium containing steel, amounting 5%, 14 for compound alloy of vanadium and niobium, accounting 7.5%.

Apart from this, Pangang developed steel grades like 20MnVB gear steel is widely used in automobile industry due to its good toughness.

High-pressure oxygen cylinder steel: 34Mn2V.

This is used to draw high-pressure cylinder. It requires high strength and good machinability to prevent crack occurrence during manufacturing. Pangang produced 34Mn2V oxygen cylinder steel with adoption of vanadium microalloying is within ten to twenty thousands tons per year.

Spring steel

Spring steel 55SiMnVB is developed in respond to the bad hardenability and easy orientation of carbon elimination of the former 60SiMn spring steel. When reducing carbon contents properly, small amount of vanadium and micro amount of boron can refine the grain size, improve the strength, toughness and hardenability. Thus the life span of spring steel is improved by about 5 to 10 times.

3.2.3 Vanadium application in low carbon steel

Vanadium exists as V_4C_3, VN in steel, usually in fine particles. It is enough to restrain the boundary movement and grain growth. Vanadium nitride and carbide precipitation function in steel as strengthening medium. Vanadium functions in low carbon steel: are mainly to refine grain size, to increase strength, to reduce the brittle-ductile transition temperature, and to improve the weldability significantly. High strength vanadium micro alloyed steel has been widely used in manufacturing of train cars, high strength automobile structures, pipelines for petroleum and gas transportation, vanadium bearing construction steel, etc..

Steel for train cars

In the manufacture of train car in China, vanadium containing micro alloyed steel is also widely applied. All the main frames of train cars are adopting the 09V steel grade produced by Pangang. The mechanical properties are as follows: the strength (σ_s)≥ 294Mpa, σ_b ≥441 MPa, $a_{k\ (ambient\ temperature)} \geq$ 58.5 J/cm^2 , $a_{k\text{-}40} \geq$ 35 J/cm^2, and good weldability. The total production of 09V steel from 1992 to 1998 is 430,000 tons.

High strength hot rolled vanadium-containing steel plate for automobile

High strength hot rolled steel plate finds wide applications in medium and light trucks, and mainly used to manufacture automobile frame and various beam parts for the car body, fender guard, suspension beam for the engine, wheel hub and rim etc. They all require good toughness, processability and weldability.

With adoption of vanadium microalloying, Pangang has developed series of automobile beam plates, of which the tensile strength is from 370 MPa to 510 MPa. This series of automobile beam plates have improved the processability and safety, reduced the brittle failure transition temperature. After being put into market, they have won favors from customers with the excellent superiority in good processability and homogeneous strength since 1994. Till now, the productions have accumulated up to 110,000 tons. For references, please see figure 12.

Vanadium-containing Pipeline steel

The demands of worldwide resource development and transportation industry are growing. Both the applications and quantities of transportation pipelines are continuously increasing as to impose great pressures on transportation pipelines. Among pipelines for petroleum and gas, the using amount of gas pipelines is increasing quite rapidly. The requirements for high performance pipeline steel are unceasingly increasing, too.

The development of pipeline steel started from 1993. Now X42-X60 steel grades have been developed, and X65, X70 are in trial production. Pipeline steel grades of Pangnag are mainly vanadium micro alloyed, and are together processed with other multi alloying elements. They have excellent toughness and weldability and are quite welcomed by the users. Till now, the productions have been accumulated up to about 150,000 tons. See details in figure 13.

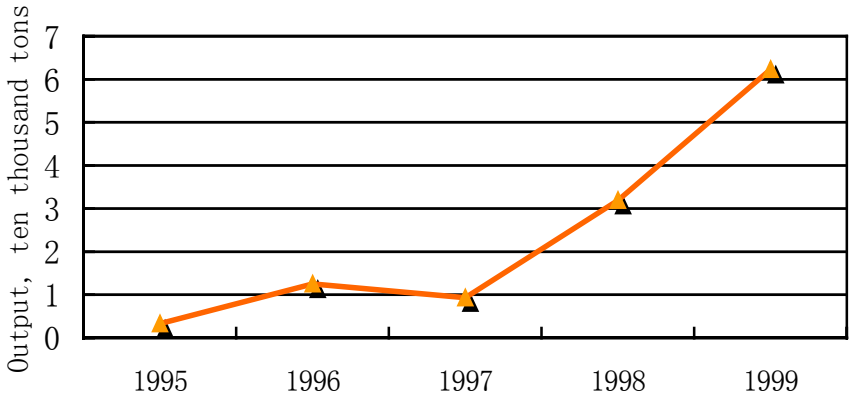


Figure 12 Automobile steel production in Pangang in the past years.

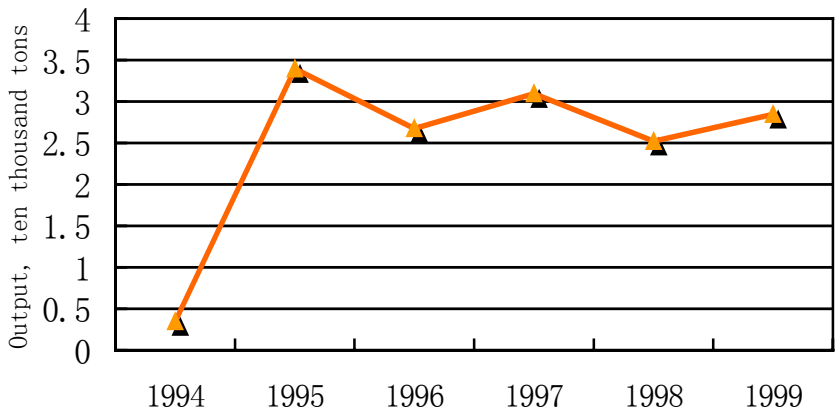


Figure 13 Pipeline steel productions of Pangang in the past years

Construction steel

It is especially worthwhile to note the applications in construction steel. The developed countries are normally using high strength rebars of above 400Mpa. While China, basically is using grade II, low strength rebars of 20MnSi steel. Vanadium microalloying is an excellent way for making high strength rebars. Vanadium-contained rebars produced by Pangang and many other domestic manufacturers are successfully applied in Xiaolangdi, Dayawan nuclear station and construction projects like high buildings in many cities in China. Vanadium containing steel, with its low cost and high strength, is good in strain ageing resistance and weldablity, and low-cycle fatigue resistance.

Ministry of the State Construction, together with Bureau of Metallurgical Industry, has done a lot in popularizing vanadium-containing rebars. Represented by Capital conference this year, in China among the annual 20 million tons construction rebars, more and more will be of vanadium containing rebars. Applications of vanadium containing steel in China will have great prospects.

Vanadium containing ship building plate

Pangang has developed vanadium microalloying ship plate (AH36) with high strength. Because of the fine toughness and plasticity and its low brittle-ductile transition temperature, it has got certifications from the British Lloyd these days; that is to say, it has obtained the international passport, too.

In conclusion, vanadium microalloyed steel has great prospects in application in Pangang. We will develop and produce market demanded vanadium microalloy steel to contribute the development of vanadium industry.

3.3 Research and development in vanadium containing steel by Pangang

Pangang has carried out a lot of works in developing new steel grades, and in researches on function mechanism of vanadium in iron and steel. In the end of 1970s, the low alloy steel rate in Pangang was not even up to 1%.

Through 20 years' efforts, the developed and converted low alloy steel grades are more than 50, in which there are 19 microalloy steel grades. In 1999, steel output of Pangang was 3.30 million tons, in which 1.22 million tons are low alloyed steel, including microalloy steel, the rate of low alloy steel was up to 40%. A serial of vanadium microalloy steel grades of low, medium and high carbon have been developed.

At the time of developing and trial producing vanadium containing low alloy and micro alloy steel, Pangang has carried out a lot of foundation works on mechanical properties and application performances of vanadium-bearing steel, and has fulfilled research works such as: "Basic research on the process of on-line heat treated for rails ", "Effects of the remaining vanadium on the rail properties", "Applications of vanadium and VN alloy in non QT steel". Meanwhile, with the support of VANITEC, Pangang has carried out researches on the topics such as "The use of vanadium in 1100 MPa heavy rail steels", "Effects of vanadium on the weldability of high strength rail steels", "Research on the application of vanadium in spring steel". Through doing the research works, it is made clear that the function principle of vanadium in improving the mechanical properties and application performances, and the optimized routes of using vanadium in strengthening different steel grades. All these works have made Pangang be able to grasp the specialized mature techniques like using vanadium micro alloying, heat-treatment strengthening and comprehensive strengthening to produce steel for heavy rail, pipeline and automobile frame structure. Research, development and applications of vanadium containing steel have become the important fields of technical creations in Pangang.

4. Vanadium application in non-steel industries

The applications of vanadium in non-steel industry in China are not much. Viewing from the total consumptions, the annual consumptions, calculated as metal vanadium is less than 300 tons, only 10% of the total amounts. It is the potential markets to be developed.

1) Vanadium catalyst

Some chemical industry companies produce various vanadium catalysts, such as SMV, AMV, SAV, VCl_3 etc. The consumptions of V_2O_5 are around 400 tons/year.

2) Vanadium-containing ferro alloy and metal vanadium

Alloys like vanadium and titanium etc. are used to produce alloy materials for aerospace uses like Ti6A14V ingot, bar and plate. The annual consumption is around 50 tons.

3) Development of vanadium battery

In recent years, some domestic institutes have done laboratory researches in developing vanadium battery. However, there is still a long distance away from industrialization.

4) Vanadium pigment: the vanadium

The developed bismuth vanadate yellow, bismuth molybdenum-vanadate yellow is in experimental applications. They are characterized with purity color, high covering capacity, and climate & heat resistance, and are used for making up non-toxicity yellow pain for automobile or for building coatings. The prospects are predicted to be well.

5) Development of vanadium oxide

The domestic demand for high purity V_2O_5 is around 100 tons. V_2O_4 membrane for energy saving, environment protection and military purpose have been obtained in samples in laboratory, but still needs further development in application.

Pangang has always paid attentions to and participated the development and applications of vanadium cell, vanadium oxide function membrane, and vanadium use in aerospace industry, and has carried out a lot of research and test works in vanadium cell, alumni-vanadium alloy and membrane of vanadium oxide.

5. Market and prospects of vanadium

History and present conditions of vanadium market

World vanadium consumption increases from 20,400 tons per year in 1991 to 38,000 tons per year in 1997, and little down to 36,000 tons in 1998. This shows that demands are growing well. The main demands come from the increasing steel output. Achievements of steel techniques result in the rising demands for high strength and low alloy. steel. Figure 14 is clearly indicating the fact that the increasing of the total vanadium consumption is in conformity with that of the world steel output and the consumption strength of vanadium in steel.

Viewing from the recent period, though the increasing demands for petroleum and natural gas transportation results in the increasing requirements for pipeline steel attributing to raising the vanadium demands. Because the production capacity is relatively more than enough, and some new projects like Windimurra are putting into production continuously. Therefore, the vanadium amount is generally oversupplied. At present, the price is regulating at a low point, another historical valley. Figure 15 is the price trends of world V_2O_5 in history. Figure 16 is showing the price trends of FeV in recent few years.

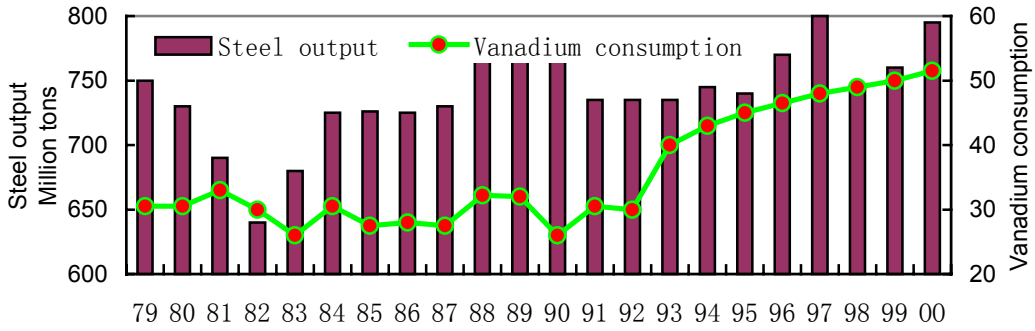


Figure 14 World steel output and vanadium consumption since 1979

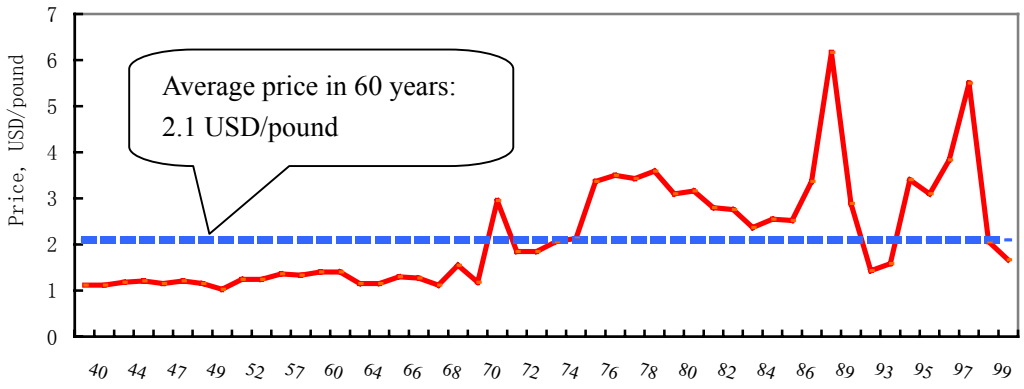


Figure 15 Price trends of world V_2O_5 in history

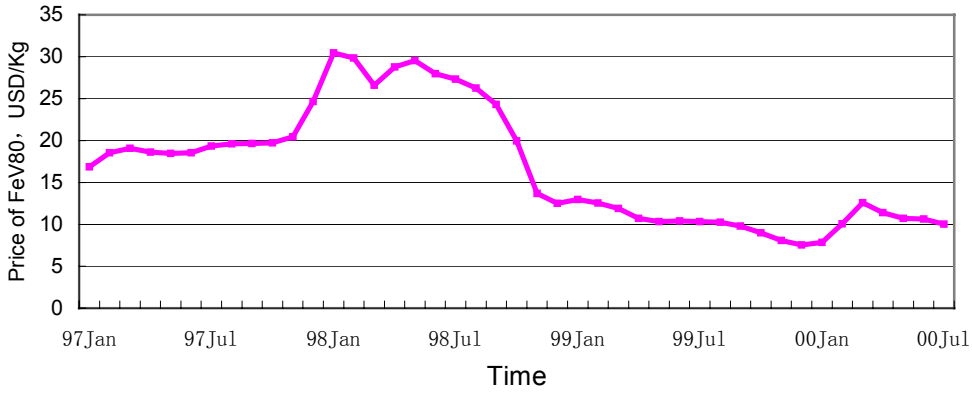


Figure 16 Price trend of world ferro-vanadium since 1997

Prospects and suggestions of vanadium market

The following reasons will determine that vanadium market will have better development.

Firstly other materials, especially plastics, alumni-plastic compound and ceramic materials have substitution functions for steel materials. This will force the steel industry to consider developing high strength and light weighted materials. Therefore, as an important microalloy element, vanadium will have opportunities to be further developed. Especially in China, construction steel, pipeline steel, vanadium bearing heavy rail steel, automobile structure steel and non-QT steel etc. are more potential.

Secondly, steel materials will dominate the markets of structure materials. In developing countries, steel products are increasing.

Thirdly, vanadium-strengthening effects in steel are under further research. For example, it's reported in the British Metal Bulletin that Bill Stasco has developed new tool steel CPM Rex 121 containing vanadium and cobalt, the performances are extraordinary with the integration of highest wear resistance, and red hardenability, better red hardenability than

other high-speed steel. CPM Rex 121 has great application prospects.

Fourthly, vanadium applications in non-steel industries, especially in vanadium cell, alumni-vanadium alloy, vanadium oxide membrane etc. have raised wide attentions. There are great potentials. According to the estimations of Roskill of U.K. that within the next ten years, the market capacity is about 10,000 tons of V_2O_5 per year. Looking from the long runs, the development of vanadium is facing fine opportunities.

6. Summary

1) Vanadium as an important metal, the applications in special steel, low alloy steel, and micro alloy steel have obvious technical and economic superiority. Apart from its wide applications in steel industry, vanadium also has wide applications in other functional materials

2) Relying on their own efforts, Chinese vanadium producing enterprises, growing out of nothing, step by step, have achieved great development in vanadium industries. China has become one of the major vanadium producing countries. Pangang has become an important vanadium producing enterprise in the world. Chinese technicians have carried out a lot of creative works in vanadium research, development, processing, applications, and have achieved a lot important successes. Now we can say, China can produce any kind of vanadium products available in the world. Though China has made great progresses, if compared with developed countries, if compared with that of No.41 element niobium, we still have a long way to go. That is to say, we have both great potentials and many works to do to develop the potential vanadium markets in China.

3) In order to promote vanadium applications in China, Pangang is willing to try his efforts together with counterparts and friends both at home and abroad.

We welcome experts abroad, with the assistance of VANITEC to come to China to guide and help researches on vanadium applications.

We are willing to cooperate with domestic customers, university and research institutes in research and development of vanadium. We are willing to fund the research and development on vanadium projects in good sense, too.

We have clarified policy targeting stable vanadium price to protect interests of vanadium customer in the unceasing fluctuation vanadium market.

We are willing to provide vanadium customers with technical services in various aspects

We have established an incentive fund for vanadium applications specialized in awarding groups and individuals for their excellent success in vanadium research and applications

We believe that with the efforts of everybody sitting here and of friends both at home and abroad. The development and application of China vanadium industry will have more brighter prospects.